BROOKHAVEN
NATIONAL LABORATORY

BNL-90172-2009-CP

Opto-Electrical Characterization and X-Ray Mapping of Large-Volume Cadmium Zinc Telluride Radiation Detectors

G. Yang, A.E. Bolotnikov, G.S. Camarda, Y. Cui, A. Hossain, H.W. Yao, K. Kim, and R.B. James

Presented at the 2009 MRS Spring Meeting
San Francisco, California
April 13-17, 2009

May 2009

Nonproliferation and National Security Department

Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
www.bnl.gov

DISCLAIMER

Opto-electrical characterization and X-ray mapping of large-volume cadmium zinc telluride radiation detectors

G. Yang, A. E. Bolotnikov, G. S. Camarda, Y. Cui, A. Hossain, H. W. Yao, K. Kim and R. B. James

Brookhaven National Laboratory, Upton, NY 11973, U.S.A.

ABSTRACT

Large-volume cadmium zinc telluride (CZT) radiation detectors would greatly improve radiation detection capabilities and, therefore, attract extensive scientific and commercial interests. CZT crystals with volumes as large as hundreds of centimeters can be achieved today due to improvements in the crystal growth technology. However, the poor performance of large-volume CZT detectors is still a challenging problem affecting the commercialization of CZT detectors and imaging arrays. We have employed Pockels effect measurements and synchrotron X-ray mapping techniques to investigate the performance-limiting factors for large-volume CZT detectors. Experimental results with the above characterization methods reveal the non-uniform distribution of internal electric field of large-volume CZT detectors, which help us to better understand the responsible mechanism for the insufficient carrier collection in large-volume CZT detectors.

INTRODUCTION

Cadmium zinc telluride (CZT) has been considered a promising material for room-temperature nuclear radiation detection, since it provides high detection-efficiency and good energy-resolution without a complicated cooling system [1-3]. Since the first practical CZT gamma-ray detector reported in 1992 [2], there have been many advances in the performance of the devices. However, most of previous investigations were focused on small-volume CZT detectors because of the limited availability of large-volume CZT single crystals. Actually large-volume CZT detectors are always desired because they substantially improve the detection-efficiency and reduce the measurement time, which are especially important in hand-held gamma-ray spectrometers, medical imaging systems and astrophysics experiments. Unfortunately, even though recent developments of crystal growth techniques provide a better availability of large-volume CZT crystals, it is still difficult to fabricate large-volume CZT detectors with high carrier collection efficiency. An important parameter that substantially affects the carrier collection efficiency and, therefore, the performance of CZT detectors, is the distribution of the internal electrical field; a uniform distribution is always desirable. However, to our knowledge, until now there are few reports to investigate the electric field distribution of large-volume CZT detectors. In this work, we employed a Pockels effect (PE) measurement system and synchrotron X-ray mapping technique to investigate the electric field distribution of a large-volume CZT detector. To avoid the complexity introduced by different contact configurations, our research is focused on Au–CZT planar detectors, because the planar configuration of contacts is the basic one used for commercial nuclear radiation detectors. The understanding of the distribution of internal electric field of planar detectors is also meaningful to other detectors with different contact configurations.

EXPERIMENT

A large-volume CZT crystal, 10 x10 x 10 mm^3, was investigated in this work, which was grown by the modified low-pressure Bridgman method. Following mechanical polishing by 0.05-µm particle-size alumina suspension and chemical polishing by 2% bromine-methanol solution, Au was deposited on the top surface and the bottom surface of the CZT sample. In this way a planar CZT detector was fabricated. To describe the distribution of internal electric field more clearly, we set up an x-y-z coordinates relative to the position of the CZT detector (shown in figure 1). Next we employed a PE measurement system, illustrated in figure 2, to reflect the corresponding lateral distribution, i.e. z-direction distribution, of the internal electric field. In this system, a collimated Xe lamp with a 950-nm infra-red (IR) filter illuminated the entire lateral surface of the CZT detector. Two linear polarizers separately acted as the polarizer and the analyzer. The transmitted light was focused on a charge coupled device (CCD) camera controlled by SynerJY software and then generated the PE images.

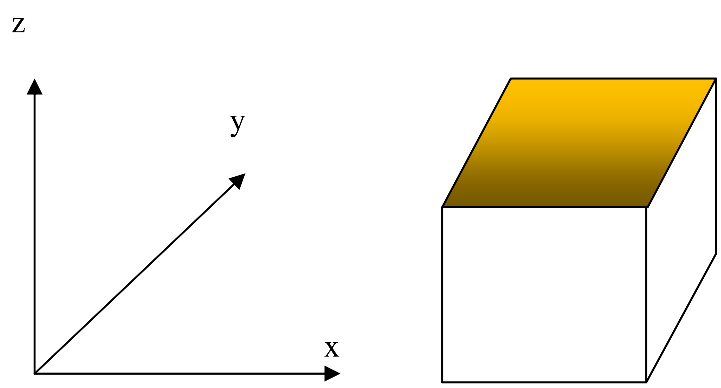

Figure 1. x-y-z coordinates for the description of internal electric field of the large-volume CZT detector

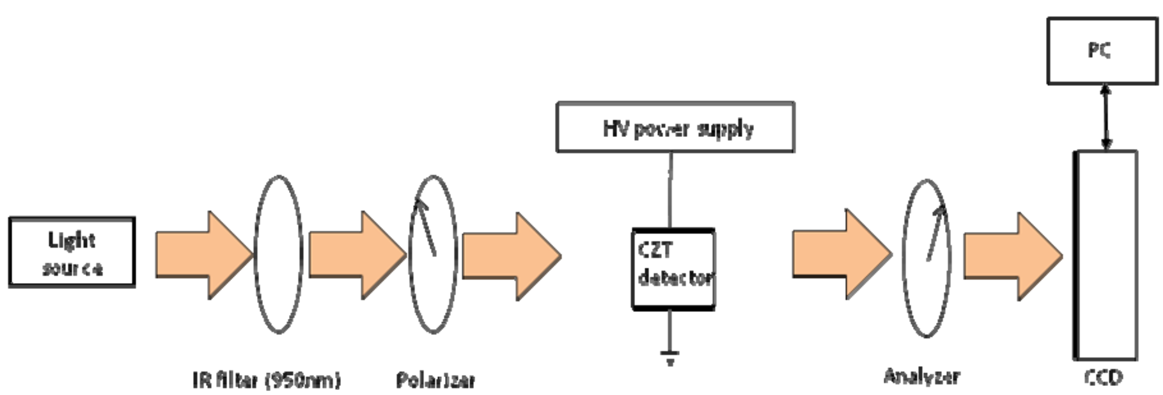

Figure 2. Schematic diagram of the Pockels effect measurement system

During the X-ray mapping measurements at Brookhaven's National Synchrotron Light Source (NSLS), an X-ray beam from a synchrotron radiation ring, with a spot size of 10x10 μm^2, was used to irradiate the CZT detector. For each position of the beam, the corresponding energy spectra and its associated information (i.e., pulse height, photopeak position, and FWHM) were collected. By raster-scanning the CZT detector in the x- and y-directions and plotting the detector's photopeak positions over its entire area, we acquired X-ray response maps. Because the response is related to charge collection, and also strongly affected by the internal electric field, such measurements yield information on the field's two-dimensional distribution (x-y direction distribution).

RESULTS AND DISCUSSIONS

In the PE measurement, the top planar electrode and the bottom planar electrode were respectively treated as the anode and the cathode of CZT detector. Before applying the bias voltage, the PE image is completely dark, indicating there is no leakage light disturbance during this measurement. Figure 3 shows the PE image of the CZT detector with a bias voltage of +2500V. According to Guenther [4], the intensity of transmitted light passing through the crossed polarizer and analyzer can be described by

$$I = I_0 \sin^2 (\frac{\pi\, n_0^3 rd}{\lambda} E),$$

(1)

where I_0 is the maximum light intensity passing through uncrossed polarizers, n_0 is the field-free refractive index, r is the linear electro-optic coefficient for CZT, d is the light path length through CZT crystal, λ is the free space wavelength of the illuminated IR light, and E is the mean electric-field along the optical path.

Since $\frac{\pi\, n_0^3 rd}{\lambda} E << 1$ [5], we have

$$I \approx I_0 (\frac{\pi\, n_0^3 rd}{\lambda} E)^2 \propto E^2$$

(2)

and

$$E \propto \sqrt{I}$$

(3)

As a result, the intensity distribution of the PE image indicates the lateral distribution of the internal electric field. From figure 3, one can see there are obvious changes of the internal electric field when a bias voltage of +2500V is applied. The amount of photon counts indicates that the intensity of the internal electric field was enhanced with increasing bias voltage. More importantly, we found the distribution of the internal electrical field is not uniform; the internal electric field firstly increases laterally from the anode towards the cathode until it arrives at the maximum value, which is approximately located on the one third of the full height, then generally decreases towards the cathode. This behavior is somewhat similar with the internal electric field in CdTe detector equipped with In and Pt contacts [6]. To further achieve the details of internal electric field distribution, we also plotted the intensity distribution from the left side to the right side (along C-D line in figure 3) and observed another interesting phenomenon.

Compared with the central section, the internal electric field is much stronger near the left edge and right edge. In other words, the strongest electric field was ‘defocused’ from the center toward both edges when the bias voltage of +2500V was applied.

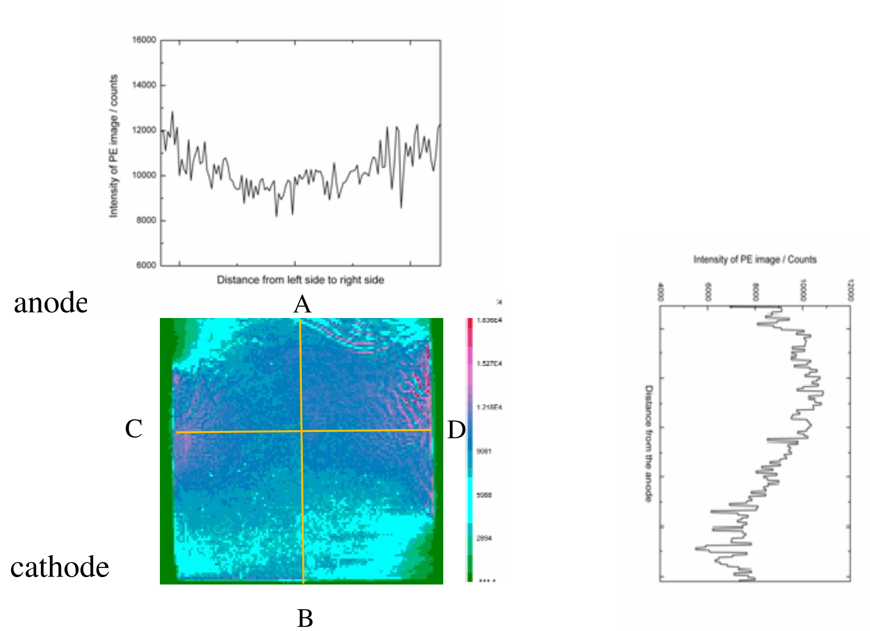

Figure 3. PE image of the large-volume CZT detector under the bias voltage of +2500V

To address this issue, we further employed the micron-scale X-ray mapping system developed at NSLS to investigate the two-dimensional distribution of the internal electric field (x-y directions). Figure 4 shows the X-ray response map of the large-volume CZT detector, where a positive bias voltage of 1000V was applied on both electrodes and a synchrotron beam of 26.9-keV X-rays was incident on the sample. Obviously, the central section of the X-ray map is uniformly white, while the surrounding edges are grey, even dark. It means the internal electric field near the edges is not uniform, and a poorer carrier collection was incurred in these edge regions. This observation is consistent with the above ‘defocusing phenomenon” revealed by Pockels effect measurement. We consider it is due to the fact that the electrostatic potential on the detector’s side surfaces decreases faster than the electrostatic potential along the detector’s axis, which result in the field lines strongly bent towards the side surfaces. Clearly, in this case, the carriers generated by incident particles near the edges are driven to the side surface, where they become trapped. As a result, this “defocusing” electric field causes an undesirable charge loss near the device’s edges in large-volume CZT detectors.

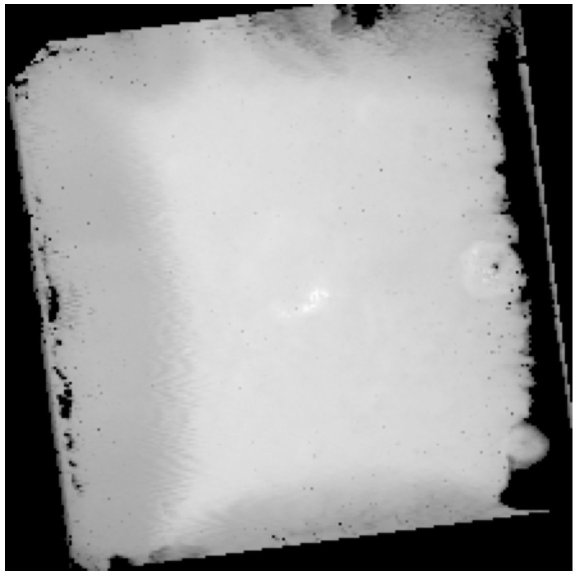

Figure 4. X-ray response map of the large-volume CZT detector

CONCLUSIONS

Pockels effect measurements and a synchrotron X-ray mapping technique were used to investigate the internal electric field of large-volume CZT radiation detectors. The experimental results indicate that the internal electric field in the large-volume CZT detector is non-uniform, and a defocusing effect of the field exists. For achieving better carrier collection efficiency, it is necessary to improve sample surface processing techniques and/or explore new device designs to correct the non-uniformity of the internal electric field of large-volume CZT detectors.

ACKNOWLEDGMENTS

This work was supported by US Department of Energy, Office of Nonproliferation Research and Development, NA-22. The manuscript has been authored by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH1-886 with the U.S. Department of Energy. The United States Government retains, and the publisher, by accepting the article for publication, acknowledges, a worldwide license to publish or reproduce the published form of this manuscript, or allow others to do so, for the United States Government purposes.

REFERENCES

1. R. B. James, T. E. Schlesinger, J. C. Lund, and M. Schieber, Semiconductors for Room Temperature Nuclear Detector Applications, Academic Press, New York, 1995, Vol. 43,
pp. 334.
2. F. P. Doty, J. F. Butler, J. F. Schetzina and K. A. Bowers, J. Vac. Sci. Technol., B10, 1418 (1992).
3. G. Yang, A. E. Bolotnikov, Y. Cui, G. S. Camarda, A. Hossain, and R. B. James, J. Cryst. Growth, 311, 99 (2008).

4. R. Guenther, Modern Optics (New York: John Wiley & Sons, Inc., 1990), pp. 569-590.
5. H. W. Yao, R. J. Anderson, and R. B. James, Proc. SPIE, 3115, 62 (1997).
6. A. Cola, I. Farella, A. M. Mancini, and A. Donati, “Electric Field Properties of CdTe Nuclear Detectors”, IEEE Trans. Nucl. Sci., 54, 868 (2007).